

FINAL REPORT

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**MAXIMIZING THE ECONOMIC AND ENVIRONMENTAL
BENEFIT OF LAND APPLICATION OF ANIMAL MANURES**

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Saskatchewan

Summary

A four year (1997-2000) study of the effects of different rates, methods and sequences of application of liquid swine effluent and solid cattle manure was conducted in the Black soil zone, east-central Saskatchewan at two sites: Dixon and Burr. The effects on soil available nutrients, crop yield, nutrient utilization, deep leaching, and nitrous oxide evolution were assessed over the four years. An economic analyses of the net returns from use of manure was conducted. Manure application recommendation software (MARC 2001, ETL Labs PC Farm Manure Management Module) was developed using information obtained from field, laboratory and economic studies. Extension of the information was accomplished through over seventy presentations at conferences, field days, seminars and scientific publications, reaching an estimated audience of several thousand producers and livestock industry people. Fact sheets on the management of manure as a fertilizer were also produced and distributed. Based on the results of this study, we are able to conclude that when manure is applied at recommended rates which match the crop nutrient requirements over time, and injected to reduce volatile nutrient losses, good economic crop responses to the manure nutrients can be anticipated, with minimal manure nutrient escape to the environment. Liquid swine effluent behaves more similar to commercial inorganic fertilizer due to its high proportion of nutrient in immediately plant available form while solid cattle manures contain more nutrient in organic forms which are more slowly released over time.

Technical Report

Note: Specific details of the experimental work completed over the past four years are provided in the seven previous six month progress reports, as well as in the various publications and conference proceedings and theses listed in the information sharing section. Therefore, this section is intended to provide general information that covers the scope of the work completed over the last four years.

Background and Objectives

The project objective is, through field and laboratory studies, to provide information that will enable the livestock industry and producers in Saskatchewan to maximize the agronomic, economic and environmental benefits received from land application of animal manures.

Project Activities and Achievements

- 1) Field Studies: Collection of four years of data from fifteen treatments at two field research sites in the Black soil zone of east-central Saskatchewan: Dixon and Burr. The Dixon site is situated on a Black Chernozem (Cudworth association) of loamy textured and is considered to represent a good typical agricultural soil of the region.

The Burr site is situated on a Black Chernozem (Meota association) of sandy loam texture underlain by a gravel lens of variable depth with significant sub-surface salinity and is considered to represent a typical marginal agricultural soil of the region.

Various treatment combinations of liquid swine effluent, solid cattle manure and urea were applied over a four year period. A summary of the treatments is provided in Table 1.

Table 1. Manure and Fertilizer Application Regimes for the 1997, 1998, 1999 and 2000 Growing Seasons at Burr and Dixon, Sask.

Swine manure						Cattle manure					
Tri	'97	'98	'99	'00		Tri	'97	'98	'99	'00	
1	0	0	0	0	No injection	1	0	0	0	0	Check with incorporation
2	0	0	0	0	Injection pass @ 12"	2	1	0	0	1	Cattle Broadcast/incorporated
3	1	0	0	1	Swine Injection @ 12"	3	1	1	1	1	Cattle Broadcast/incorporated
4	1	1	1	1	Swine Injection @ 12"	4	2	0	0	2	Cattle Broadcast/incorporated
5	2	0	0	2	Swine Injection @ 12"	5	2	0	2	2	Cattle Broadcast/incorporated
6	2	0	2	2	Swine injection @ 12"	6	2	2	2	2	Cattle Broadcast/incorporated
7	2	2	2	2	Swine Injection @ 12"	7	4	0	0	4	Cattle Broadcast/incorporated
8	4	0	0	4	Swine Injection @ 12"	8	4	4	4	4	Cattle Broadcast/incorporated
9	4	4	4	4	Swine Injection @ 12"	9	1	1	1	1	Cattle Broadcast/delayed-incorp.
10	1	1	1	1	Swine Sweep @ 24"	10	1	1	1	1	Urea Banded
11	1	1	1	1	Swine Spiked & straight boot	11	2	2	2	2	Urea Banded
12	1	1	1	1	Swine Broadcast & incorporated	12	4	4	4	4	Urea Banded
13	1	1	1	1	Urea Banded						
14	2	2	2	2	Urea Banded						
15	4	4	4	4	Urea Banded						

Key: 1 Low
2 Medium
4 High

Quantities of manure N applied for the 1997 to 2000 growing seasons are given in Table 2. Quantities of other nutrients ie: P, K, S, micronutrients applied were also calculated from the complete macro and micronutrient analyses of manure samples made each year. This data is contained in various publications such as Julian Charles MSc thesis, Dept. of Soil Science, 1999 and is on file with the principle investigator, Dr. Jeff Schoenau. Urea fertilizer application rates were 50, 100 and 200 kg N / ha for the low, medium and high treatment levels, respectively. Both manure and urea fertilizer applications were made in the preceding fall of each growing season by Prairie Agriculture Machinery Institute using a chisel plow type applicator placing the injected liquid effluent at a depth of ~ 10 cm, same as for the banded urea. Solid cattle manure was broadcast across the plots by hand and incorporated using a rotovator.

Table 2. Total N Applied in the Swine and Cattle Manure Studies at the Low, Medium and High Application Rates in the 1997, 1998, 1999 and 2000 Growing Seasons at Burr and Dixon.

	Swine manure								Cattle manure							
	1997		1998		1999		2000		1997		1998		1999		2000	
	Burr	Dixon	Burr	Dixon	Burr	Dixon	Burr	Dixon	Burr	Dixon	Burr	Dixon	Burr	Dixon	Burr	Dixon
	(kg N ha ⁻¹)								(kg N ha ⁻¹)							
Code																
Check	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Low	1	204	74	46	51	142	97	97	94	228	121	104	104	74	69	113
Medium	2	395	147	92	102	285	195	194	188	456	242	208	208	149	138	226
High	4	790	295	183	204	569	390	388	376	912	484	416	416	298	276	452

Soil available (0-60 cm) ammonium and nitrate contents were measured in all plots in the spring and the fall after harvest each year. Fall sampling included deep sampling (60-90cm and 90-120 cm) to look for any deep leached nitrate. In the spring, measurements of extractable P,K, electrical conductivity and pH were made on 0-30cm samples. In 2000, samples were collected from manured plots and analyzed for physical properties: sodicity, salinity, aggregation, and bulk density.

The cropping sequence used at the plots was the same as that employed by the farmer on the rest of the field and comprised a grain and oilseed crop rotation sequence typical of the region: 1997, argentine canola; 1998, hard red spring wheat; 1999, hullless barley; 2000, argentine canola. Harvest of the plots involved taking square meter samples of grain and straw. Grain and straw yields were determined and the grain and straw analyzed for nutrient content to determine nutrient uptake and recovery i.e. nitrogen use efficiency.

After application in the fall and several times over the growing season, measurements were made of denitrification (nitrous oxide flux) using canisters in the field, conducted by Drs. Farrell and Knight. The plots also served as a study area for an ADF project investigating the impact of manure application on microbial populations, including plant and human pathogens (ADF project 97000294) by Drs. Schoenau and de Freitas.

2) Controlled Environment and Laboratory Studies: A number of greenhouse and laboratory studies were conducted by Drs Qian and Schoenau on manure nutrient cycling to better understand the forms, behavior and fate of manure nutrients in the soil environment under controlled conditions. These studies included: 1) a comparison of the availability of nitrogen in liquid swine effluent compared to commercial urea fertilizer (97-98); 2) evaluation of the fate of phosphorus applied as liquid swine effluent in Saskatchewan soils (98-99) and 3) determining the availability of nitrogen in different solid manure sources and its relationship to manure origin and C:N ratio (99-00).

3) Economic Analyses: Using the yield responses observed from addition of swine effluent, cattle manure and urea fertilizer in the field plots over the three years, along with estimated hauling and application costs, the economic returns and hauling distance of the manure was determined by C. Nagy and Dr. D. Schoney of the U of S Ag Economics Department.

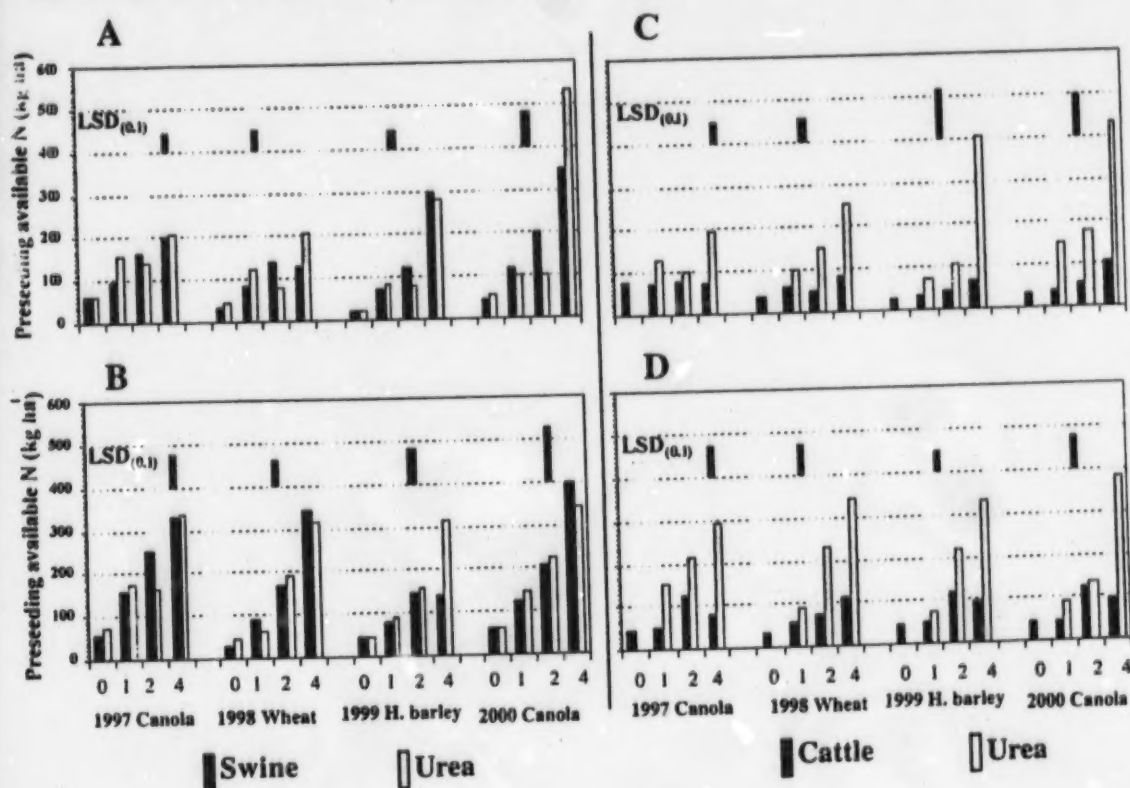
4) Manure Application Recommendation Software: Using key information obtained from activities 1, 2 and 3 above on such factors as forms and relative availability of nutrients in manure, crop responses and utilization of manure nutrients and value of manure nutrients, two software programs were developed to enable manure users to determine the appropriate rate of manure to apply to meet the crop nutrient requirement.

5) Manure Use Extension and Education: Knowledge and information from activities 1,2,3 and 4 has been extensively disseminated to agriculture industry, scientific community and general public (see information sharing section).

General Discussion of Activities

1. Field Studies: Swine effluent was effective in increasing the available nitrogen in the soil profile measured in the spring after application the fall before (A and B in Figure 1). Overall, for the swine effluent used in this study, we found that the availability of nitrogen in the year of application was about 60% to 70% that of urea.

Figure 1. Pre-seeding available N in 1997, 1998, 1999 and 2000, respectively in the swine manure study at Dixon (A) and Burr (B); and in the cattle manure study at Dixon (C) and Burr (D).

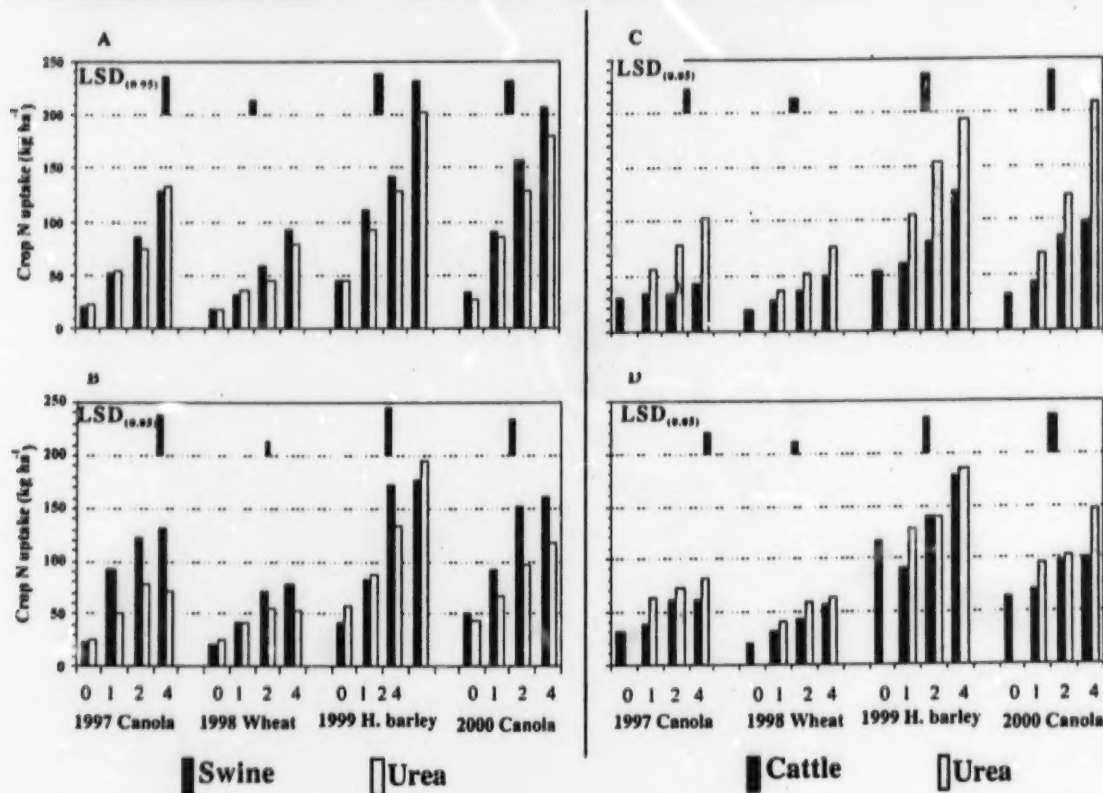


When applied annually at 75 to 150 kg N per hectare per year (treatments 1 and 2 in Figure 1), the liquid swine effluent and urea showed little evidence of accumulation of inorganic N in the profile over the four years. However, when applied at the high rates: 200 to 300 kg N per hectare per year (treatment 4), a cumulative effect was observed at the Dixon site. As well, the high rates also showed some evidence of leaching of nitrate below the 60 cm depth into the 60-90 cm and 90-120 cm depths. It is evident that application of swine effluent nitrogen at rates which greatly exceed the crop nitrogen uptake potential over a number of years can result in accumulation of inorganic nitrogen in the soil profile which increases the risk of deep leaching of nitrate.

At the Dixon site, cattle manure had limited effect on pre-seeding available N in the soil profile (C and D in Figure 1) in all four growing seasons. This is attributed to the fact that the cattle manure was feed-lot penning material with significant amounts of straw mixed with the fecal material. As observed in the controlled environment studies and discussed in section 2 below, cattle manure with bedding releases its nitrogen into available forms much more slowly than liquid swine effluent. Although no elevation in pre-seeding available N was observed in 1997 at Dixon, increasing rates of cattle manure increased pre-seeding available N in subsequent years although these increments were not statistically significant. Similar results were obtained at Burr, except that elevation of pre-seeding available N was evident in 1997, due to a high application rate used at this site in the first year.

Increasing rates of swine and cattle manure significantly enhanced crop N uptake in all the four crops (Fig. 2). The main variable associated with crop yield increase from added manure, particularly swine effluent, was identified to be increased supplies of available nitrogen. At both Dixon and Burr, crop N uptake in swine manure plots approached that of the urea plots. At Dixon, crop N uptake in urea treated plots was higher than in the cattle manure plots, consistent with the slower release of available nitrogen from the cattle manure.

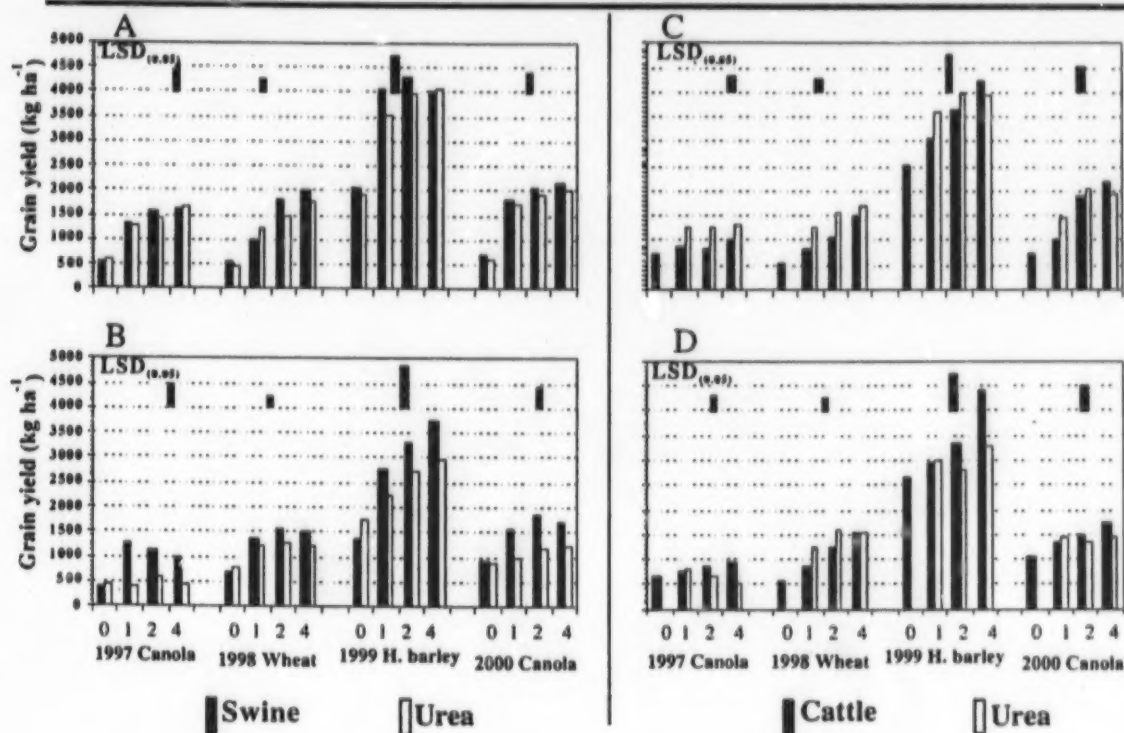
Figure 2. Nitrogen uptake by canola, wheat, hulless barley and canola in 1997, 1998, 1999 and 2000 in the swine manure study at Dixon (A) and Burr (B); and in the cattle manure study at Dixon (C) and Burr (D).



Overall, grain yields were similar between swine effluent treated and urea plots over the four years of the study (Figure 3). It is important to recognize that the low, medium and high rates of swine effluent added significantly more total nitrogen (about 1/3 more) than the low, medium and high rates of urea in the comparison, and that the manure also added other nutrients such as phosphorus, potassium, sulfur and micronutrients which would contribute to crop response. Overall, annual applications of 75 to 150 kg N / ha of swine effluent (treatments 1 and 2 in figure 3) were sufficient to produce maximum yields of the crops. Annual applications larger than 200 kg N / ha should be avoided as repeated yearly applications at these rates resulted in accumulation of inorganic N in the soil, evidence of some deeper leaching, higher denitrification losses, and potential agronomic problems with damage to seedlings, lodging and haying off during dry years. The larger single applications of swine effluent (~ 200 kg N / ha) generally had a significant residual effect in year 2, but by the third year the residual effects were greatly diminished. Another important observation was that yields and nitrogen recovery were consistently lower in the treatment where swine effluent

was broadcast versus injected. Over the four years, the 30 cm row spacing tended to produce better yield response than the 60 cm injection spacing, due to stripping, especially in drier years.

Figure 3. Grain yield of canola, wheat, hulless barley and canola in 1997, 1998, 1999 and 2000 in the swine manure study at Dixon (A) and Burr (B), and in the cattle manure study at Dixon (C) and Burr (D).



For the cattle manure study at Dixon, the grain yields observed in the first years of cattle manure application (1997 and 1998) were lower than for the urea treatments, reflecting the lower N availability from the cattle manure. However, by the third and fourth year, the grain yields from the cattle manure plots were similar to the urea plots, likely because of mineralization and release of nutrients from previous years manure applications.

In all four crops, the effect of swine effluent addition on increasing grain protein was similar to the effect of increasing rate of urea fertilizer (Table 3). In both cases, grain protein was significantly enhanced by increasing the rate of application. Increases in grain protein are consistent with the effect of the manure on increasing the supply of available nitrogen over the growing season. Cattle manure had a lesser effect on increasing grain protein content than swine effluent or urea, reflecting the lower availability of the nitrogen in the initial years of application.

Table 3. Grain protein of canola, wheat, hulless barley and canola in 1997, 1998, 1999 and 2000 in the swine manure study (A) and the cattle manure study (B) at Burr and Dixon.

A		GRAIN PROTEIN (%)											
Trt	Source	Rate				1997 Canola		1998 Wheat		1999 H.barley		2000 Canola	
		'97	'98	'99	'00	Burr	Dixon	Burr	Dixon	Burr	Dixon	Burr	Dixon
2	Check	0	0	0	0	26.3 bc	19.6 c	14.7 c	16.2 b	10.5 d	8.9 d	24.7 b	22.1 d
4	Swine	1	1	1	1	30.7 a	20.4 c	14.8 c	15.2 bc	11.5 d	10.4 c	25.4 b	21.3 de
7	Swine	2	2	2	2	32.1 a	25.7 b	17.6 b	14.8 bc	14.6 bc	13.1 b	29.5 a	26.9 bc
9	Swine	4	4	4	4	33.0 a	29.5 a	19.6 a	18.3 a	15.1 ab	17.7 a	28.2 a	29.3 a
1	Check	0	0	0	0	24.9 c	18.6 c	15.4 c	16.2 b	11.2 d	8.8 d	23.6 b	19.7 e
13	Urea	1	1	1	1	29.5 ab	21.2 c	16.1 c	14.0 c	13.2 c	10.5 e	28.6 a	21.5 de
14	Urea	2	2	2	2	31.8 a	24.9 b	18.8 ab	15.0 bc	14.4 bc	12.9 b	28.5 a	25.9 c
15	Urea	4	4	4	4	32.3 a	28.3 ab	18.6 ab	18.7 a	16.6 a	16.5 a	28.4 a	28.8 ab

B		GRAIN PROTEIN (%)											
Trt	Source	Rate				1997 Canola		1998 Wheat		1999 H.barley		2000 Canola	
		'97	'98	'99	'00	Burr	Dixon	Burr	Dixon	Burr	Dixon	Burr	Dixon
1	Check	0	0	0	0	23.6 c	19.5 c	17.1 bc	16.0 bc	12.0 cd	9.0 e	23.9 cd	20.0 c
3	Cattle	1	1	1	1	24.2 c	19.7 c	17.0 bc	16.4 bc	11.3 d	9.0 e	22.8 d	20.4 c
6	Cattle	2	2	2	2	28.2 b	19.9 c	17.0 bc	16.8 b	12.4 cd	9.9 de	26.3 b	20.5 c
8	Cattle	4	4	4	4	27.7 b	20.3 c	18.0 ab	16.8 b	13.0 bc	11.1 c	26.5 b	20.7 c
10	Urea	1	1	1	1	29.3 ab	23.5 b	16.1 c	14.6 d	12.6 c	10.2 cd	25.3 bc	20.4 c
11	Urea	2	2	2	2	29.2 ab	27.5 a	17.9 ab	15.3 cd	13.9 b	13.2 b	28.7 a	24.6 b
12	Urea	4	4	4	4	31.4 a	29.5 a	19.0 a	19.0 a	16.2 a	16.7 a	29.6 a	30.1 a

Means followed by the same letter are not different at 0.05 level of significance.

Cumulative nitrogen use efficiency (proportion of applied nitrogen recovered in the crop), adjusted for straw N of the previous crop, tended to be somewhat lower in the swine effluent plots than in the urea plots at corresponding rates of application (Table 4). This is attributed to the fact that some of the N (~ 40% to 50%) added as swine effluent is in the organic form and is not all mineralized to available forms in the soil. As expected, nitrogen use efficiency decreased with increasing application rate of both swine manure and urea, as the crop has a finite potential for nitrogen uptake. At the low application rates, apparent nitrogen use efficiency of swine effluent nitrogen and urea fertilizer nitrogen was quite good, with about 40% to 60% of the applied N recovered in the crop. In the case of the cattle manure, most (~ 90%) of the added N is in the organic form with a high carbon: nitrogen ratio. Due to low mineralization in the initial years following application, apparent nitrogen use efficiency of the cattle manure N over the four years was significantly lower than the urea and swine effluent N. However, over time the nitrogen use efficiency of the cattle manure treatments was increasing and would be expected to continue to increase if the study was extended for a number of years. Although pre-seeding available N was not enhanced by cattle manure to the extent it was in swine effluent and urea treatments, sufficient N slowly became available to the crop to result in increased grain yield and total N uptake at both locations.

Table 4. Cumulative adjusted nitrogen use efficiency (NUE) of canola, wheat, hulless barley and canola in 1997, 1998, 1999 and 2000 in the swine manure study (A) and in the cattle manure study (B) at Burr and Dixon.

A		Cumulative Adjusted %NUE											
Trr	Source	Rate				1997 Canola		1998 Wheat		1999 H.barley		2000 Canola	
		'97	'98	'99	'00	Burr	Dixon	Burr	Dixon	Burr	Dixon	Burr	Dixon
4	Swine	1	1	1	1	33 b	43 ab	25 a	32 ab	18 ab	46 abc	23 a	43 bc
7	Swine	2	2	2	2	25 b	44 ab	17 ab	35 ab	19 ab	40 bc	21 ab	43 bc
9	Swine	4	4	4	4	14 b	36 b	9 b	27 b	10 b	33 c	11 b	29 d
13	Urea	1	1	1	1	53 a	64 a	20 ab	42 a	21 ab	58 a	22 a	62 a
14	Urea	2	2	2	2	54 a	53 ab	22 ab	33 ab	28 a	48 ab	25 a	53 ab
15	Urea	4	4	4	4	23 b	55 ab	9 b	30 ab	20 ab	43 bc	16 ab	41 c

B		Cumulative Adjusted %NUE											
Trr	Source	Rate				1997 Canola		1998 Wheat		1999 H.barley		2000 Canola	
		'97	'98	'99	'00	Burr	Dixon	Burr	Dixon	Burr	Dixon	Burr	Dixon
3	Cattle	1	1	1	1	2 d	5 c	4 c	6 c	-3 c	7 c	5 c	7 b
6	Cattle	2	2	2	2	6 d	2 c	6 c	5 c	7 bc	8 c	8 c	11 b
8	Cattle	4	4	4	4	3 d	3 c	4 c	5 c	7 bc	9 c	6 c	9 b
10	Urea	1	1	1	1	63 a	55 a	34 a	40 a	26 a	60 a	37 a	49 a
11	Urea	2	2	2	2	39 b	49 ab	23 b	33 a	21 ab	53 a	23 b	49 a
12	Urea	4	4	4	4	24 c	37 b	12 c	24 b	17 ab	36 b	19 b	40 a

Means followed by the same letter are not different at 0.05 level of significance.

The effect of the manure applications on soil extractable phosphorus in the 0-30 cm layer was also monitored in yearly spring sampling of the plots. The high annual rates of swine manure produced significant increases in extractable P over the control at the Burr site, with about 70 kg extractable P / ha in the high annual rate of swine effluent after four years versus 15 to 30 kg extractable P / ha in the controls. However, a significant effect of swine effluent on increasing extractable P was only observed at the Burr site (sandy soil, lower P sorption capacity). There was no significant effect of swine effluent application on extractable P at the Dixon site, although there was a trend towards increasing levels of extractable P with increasing application rate. The lack of large increases in soil extractable P, even after four years of repeated application of swine effluent at the high rate, is consistent with the high P sorption capacity of these soils and agrees with the controlled environment studies in which the bulk of the added manure P was found to enter more stable fractions of soil P initially. Over the four years of the study, it was observed that the phosphorus content of the manure applied was decreasing as well, possibly due to changes in feeds or feeding practices in the hog barns. Repeated cattle manure application increased extractable P levels only slightly and the increases were only significant over the control at the high rates. Despite a limited effect of added manure on extractable soil inorganic P over the four years of this study, the manure was shown to increase supplies of available P and crop P uptake in the greenhouse and in the field, likely through mineralization of organic P.

The addition of swine effluent tended to increase extractable potassium levels in the soil, but the increases were often not statistically significant. The extractable potassium assessment may not be sensitive enough to pick out significant differences over the four year time frame of the study. Cattle manure, on the other hand, resulted in significant increases in extractable K after four years of application at the high rates at both sites, with extractable K 1.5X higher in the high annual cattle

manure application than in the control. These findings suggest that cattle manure may be more effective in increasing available K in the soil than liquid swine effluent.

Repeated applications of cattle manure tended to decrease aggregate size and decrease bulk density, which can be attributed to the effect of the organic matter added (Table 5). There was a tendency for electrical conductivity, measured each spring, to be slightly higher in the hog and cattle manure treatments than in the control. High rates of urea also caused a slight elevation in electrical conductivity. The pH also tended to be slightly lower in the cattle and swine effluent plots, which is attributed to organic acids contained in, or produced by manure decomposition, as well as acidity produced during nitrification of ammonium to nitrate. The soil sodicity as revealed in the sodium adsorption ratio (SAR) measurements, also was slightly elevated in manured plots as compared to the controls. While there was a trend towards higher salinity and sodicity in plots receiving repeated manure applications, the increases after four years were not large and did not appear to have a detrimental effect on crop production. However, since manures contain sodium salts, salinity and sodicity should be monitored in soils receiving repeated applications of manure.

Table 5. Soil properties at the Burr cattle manure plots measured in the spring of 2000.

Treatment	Aggregate MWD mm	Bulk density Mg / m ³	E.C. dS/m	pH	SAR
Check	19.7	1.4	1.00	7.7	0.67
Cattle low	16.3	1.4	0.64	7.8	0.74
Cattle medium	13.8	1.2	1.88	7.8	1.66
Cattle high	16.6	1.2	1.12	7.6	1.30

No evidence of micronutrient imbalances were detected over the course of this study. Cadmium and lead concentrations in manure and plant tissue were consistently low and not related to rate of application. However, the effect of repeated manure applications over several years on bioavailability of metals in the soil deserves further attention and should be monitored.

Measurements of nitrous oxide fluxes made over each growing season in the Dixon plots receiving swine effluent and urea fertilizer revealed higher denitrification rates in the swine effluent plots compared to commercial urea fertilizer. Overall, higher denitrification rates were associated with higher rates of application. The highest denitrification rates were measured shortly after application in the fall. Soluble carbon in the manure and anaerobic microsites produced from application of liquid effluent would contribute to high initial activity of denitrifiers. By the end of the season, substrates required for denitrification are used up and soil environments under urea and manure applications converge. The nitrous oxide emissions were highly correlated with soil water content and ammonium concentration. Application of manure using rates and methods which encourage rapid and complete crop utilization of the manure ammonium nitrogen are expected to contribute to reduced losses of nitrogen by denitrification.

Controlled Environment and Laboratory Studies: A growth chamber study was conducted using soils from the Burr and Dixon control plots to evaluate how addition of urea and swine effluent affected the supply of plant available nitrogen and its relationship with plant uptake. Addition of urea and swine effluent significantly increased the supply of plant available N measured in the soil. Over 84 days, the supply of available N in the manured soil was about 40% lower than in the urea fertilized soil due to incomplete mineralization of organic N in the manure. However, plant uptake

of N was similar between manure and urea treated soils, which is attributed to other nutrients in the manure that would have enhanced root growth and plant N uptake. This is consistent with results observed in the field at the two sites.

Another study was conducted in the growth chamber to determine how swine effluent influences available P supplies in the soil. Additions of swine effluent and urea enhanced canola P uptake and led to a higher accumulation of P in the seeds. This response was more evident with the swine effluent and points to the role of swine effluent as a source of plant available phosphorus through organic P mineralization. Soil amended with swine effluent increased the supply rates of available P over time in the soil while, as expected, urea did not. A laboratory study was then completed to determine the fate of swine effluent phosphorus in the soil. This study showed that a single addition of liquid swine manure did not increase the extractable inorganic phosphorus forms in the soil, consistent with the limited increase in soil extractable P observed in the field plots. Instead, the initial fate of the P from the manure was mainly to enter moderately stable fractions such as calcium phosphate and organic P forms. However, repeated application of manure at high rates over a number of years is expected to eventual saturate the P sorption sites and lead to concomitant large increases in extractable P in the future, which has been observed in other regions such as southern Alberta after 20 years of high rates of cattle manure addition.

The final controlled environment study was conducted to compare the availability of nitrogen in different solid manure amendments, including cattle manures of different ages and origins as well as composted and fortified manures. This study revealed that addition of solid cattle manure amendments to two soils did not result in large increases in canola N uptake, with the exception of poultry manure which had a larger content of easily mineralized organic N, and a composted hog manure with supplemental fertilizer N added. The manure carbon : nitrogen ratio was observed to play a significant role, as a significant correlation between manure C:N ratio and N mineralization was found in the manure amended soils. Generally, cattle manures had little impact on short-term release of available N if the organic C: N ratio was in the range of 13-15 and tended to decrease N availability in the short-term if the organic C:N ratio was over 15. C:N ratio would be a useful parameter to measure in a solid manure sample when attempting to predict short-term N release characteristics.

3) Economic Analyses: The economic analyses revealed the highest net revenue over three years from injected swine effluent and urea applied at the low and medium rate. The net revenue for the injected swine effluent is the revenue from the crops grown minus the least cost method for manure transport and application and for the urea applications, it is the cost of banding plus the cost of urea. Overall, urea and swine effluent produced similar net returns (Table 6) when all costs were factored in, and significantly higher net returns than the control. It is important to note that high rates of swine effluent applied each year, which were associated with evidence of high nutrient loss and crop damage, produced the lowest and sometimes negative net returns. Economic or break-even hauling distances for the manure were generally in the range of two to eight kilometers away from the site of manure storage. The positive marginal return of some of the treatments indicates that grain producers would be willing to pay to have the manure hauled to gain the benefits. However, variability of returns and the carryover effects of manure further complicate the determination of an optimum hauling distance.

Table 6. Dixog site swine manure net revenue over three years and economic hauling distance.

Treatment 97-98-99 -----	Net Revenue \$/ha -----	Economic Hauling Distance km -----
0-0-0 (check)	508	
<i>Swine</i>		
1-0-0	753	1.9
1-1-1	824	8.3
2-0-0	811	10.2
2-0-2	883	3.2
2-2-2	824	3.8
4-0-0	761	4.5
4-4-4	493	-
<i>Urea</i>		
1-1-1	868	
2-2-2	925	
4-4-4	901	

4) Manure Application Recommendation Software: One program, Envirotec Laboratories PC FARM manure management module, is an addition to the fertilizer recommendation software provided by ETL labs to customers. The program uses input data from a manure analyses conducted by the lab and nutrient requirements identified by the soil test to determine the appropriate rate of manure to be applied to meet the nutrient requirement. It is designed as a simple system that is easily used by a farmer, fertilizer dealer or agrologist to quickly calculate an appropriate rate of manure to apply. The software is available from Envirotec labs in Saskatoon. The other program, Manure Application Rate Calculator (MARC 2001), is a tri-provincial effort (Alta, Sask, Manitoba) that is a modification of previous programs used in Manitoba and Ontario. This program has, in addition to calculation of rates based on manure analysis and soil testing, a number of record keeping features as well as storage, application and economic components. The MARC program is well suited to individuals involved in nutrient management planning for larger scale intensive livestock operations and is available for downloading from the Sask Ag and Food web site.

5) Manure Use Extension and Education: Activities in this area have been extensive (see information sharing section below). This has taken the form of presentations at field days and field tours held at the sites every year over the four years of the study. Many invited presentations have been made at government and industry sponsored agronomy conferences such as Agronomy Updates and Workshops, Soils and Crops Workshops, Prairie Swine Conferences, Manure Management Conferences and Scientific Society Meetings such as the Canadian Society of Soil Science and Soil Science Society of America. Publication of the information has taken the form of scientific papers in conference proceedings and scientific journals, workshop proceedings, annual reports by agencies such as Prairie Swine Center and fact sheets such as the SAF Farm Facts: Managing Manure as a Fertilizer, Nov. 2000 and the fact sheet on Impact of Swine Manure Application on Soil, Water and Human Health currently in press. Information on manure nutrient management has also been incorporated into lecture and laboratory components of classes taught in

the College of Agriculture such as Soil Fertility and Fertilizers. The project has contributed to the training of highly qualified personnel including two MSc students: Julian Charles and Bereket Assefa and two post doctoral fellows: Dr. G. Wen and Dr. P. Mooleki. Demand for expertise in the area of manure management is evident from the many requests for fact sheets and reprints of study results and requests for attendance at public meetings.

Information Sharing : Information sharing deliverables outlined in contract: field tours, manure management bulletins, computer software development, presentations at meetings and conferences have been met or exceeded.

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- 4) SAF Growing Wheat and Durum March 8, 1999 Kindersley
- 5) SAF Industry Update, January 22, 1999, Saskatoon
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Deliverables: As indicated in the contract, the following deliverables have been provided:

- (i) Manure application guidelines have been developed and presented in fact sheets, software and publications described in the information sharing section.
- (ii) Two software packages have been developed which use knowledge provided by this project: ETL labs PC Farm Manure Management Module and MARC 2001 Manure Application Rate Calculator.
- (iii) Increased knowledge of agricultural producers in handling and applying manure profitably. Several thousand individuals have received information on manure management over the past four years based on the extensive information sharing activities conducted in this project. Field tours, workshops and conferences on manure management have had excellent attendance and the University of Saskatchewan and PAMI are recognized as leaders in manure management research on the Prairies and in Canada. This knowledge has been extensively disseminated and has led to the majority of producers now applying manure at appropriate rates and using technologies such as injection to maximize nutrient recovery and minimize odor and realize maximum economic benefit.

Project Success: This project has greatly advanced our understanding of manure behavior and has enabled development of prairie-specific recommendations for optimum rates and application methods to maximize agronomic, economic and environmental benefit from the manure resource. Demand for this information in the form of requests for fact sheets, presentations, consultations and research publications has been considerable as shown in the information sharing section above.

U of S Personnel Involved

Drs. P. Mooleki, and G. Wen, post doctoral fellows
Dr. P. Qian, research associate
C. Nagy, research officer
J. Charles, B. Assefa, graduate students
S. Farkas, M. Masich, field technicians
Y. Gao, M. Qiu, N. Howse, laboratory technicians
C. Fatteicher, T. Johnson, summer students

Equipment: None

Project Photos: Submitted with progress reports.

Innovation Fund Acknowledgement:

Acknowledgement is given to AFIF support at end of papers and presentations described in Information Sharing section.

Project Public Information Materials: as described in Information Sharing section.